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Broadband X-ray spectrum of GRS 1734–292, a luminous Seyfert 1 galaxy behind the Galactic Center

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Abstract. Based on a deep survey of the Galactic Center region performed with the INTEGRAL observatory, we measured for the first time the hard X-ray (20–200 keV) spectrum of the Seyfert 1 galaxy GRS 1734−292 located in the direction of the Galactic Center. We extended the spectrum to lower energies using archival GRANAT and ASCA observations. The broadband X-ray spectrum is similar to those of other nearby luminous AGNs, having a power law shape without cutoff up to at least 100 keV.

Key words. Galaxies: Seyfert – X-rays: general

1. Introduction

The hard X-ray source GRS 1734−292, located 1.8° from the Galactic Center (GC), was discovered in 1990 by the ART-P telescope aboard the GRANAT satellite (Pavlinsky et al. 1992, 1994). The measured power-law spectrum with a photon index $\Gamma \sim 2$ and inferred X-ray luminosity ($\sim 10^{36}\,\mathrm{erg\,s^{-1}}$) assuming a GC distance were consistent with the source being a Galactic X-ray binary. However, subsequent optical spectroscopic observations surprisingly revealed (Martí et al. 1998) very strong, broad emission lines demonstrating that GRS 1734−292 is the nucleus of a Seyfert 1 galaxy at a redshift $z = 0.0214$. The galaxy itself has so far escaped observation because of ≈ 6 magnitudes of visual absorption along the line of sight through the Galactic plane.

With its X-ray luminosity approaching $10^{44}\,\mathrm{erg\,s^{-1}}$ (2–10 keV), GRS 1734−292 is one of the ∼ 5 most luminous AGNs within 100 Mpc of us (e.g. Piccinotti et al. 1982; Sazonov & Revnivtsev 2004), which makes it a very interesting object for investigation. Additional interest in GRS 1734−292 is connected with the fact (Di Cocco et al. 2004) that its position falls into the error box (∼ 0.5° radius) of the gamma-ray source 3EG J1736−2908 discovered by CGRO/EGRET (Hartman et al. 1999).

In the past, spectroscopy of GRS 1734−292 at energies above 20 keV could not be performed with collimator instruments such as RXTE/PCA, RXTE/HEXTE and BeppoSAX/PDS because of the high number density of bright sources in the GC region. The only instrument possessing the necessary angular resolution was the coded mask SIGMA telescope aboard GRANAT. However, GRS 1734−292 persistently remained below the sensitivity threshold of SIGMA and was marginally detected only during an outburst on September 15–17, 1992 (Churazov et al. 1992).

GRS 1734−292 has recently been detected with high significance by the hard X-ray imager IBIS aboard the INTEGRAL satellite (Revnivtsev et al. 2004; Bassani et al. 2004). Here we use INTEGRAL observations to obtain for the first time a high-quality X-ray spectrum of GRS 1734−292 above 20 keV and extend the spectrum to lower energies using data from previous missions.

2. Observations and data analysis

The main instruments of INTEGRAL are the hard X-ray coded mask telescope IBIS and spectrometer SPI (Winkler et al. 2003). Unfortunately, the limited angular resolution (∼ 2.5°) does not allow us to use SPI for studying GRS 1734−292, because there are several bright hard X-ray sources, including 1E 1740.4−2942, located within a few degrees of GRS 1734−292. We therefore employ the IBIS telescope (specifically the ISGRI detector) whose high angular resolution (∼ 10′) prevents source confusion.

A 30° × 30° area centered on the GC was extensively observed by INTEGRAL in August–September 2003, these observations making up an ultra-deep survey with a total exposure of ∼ 2 Ms. A total of 60 point sources were detected by IBIS/ISGRI, including GRS 1734−292 (Revnivtsev et al. 2004).

Here we have analyzed the data of the GC survey following the methods described by Revnivtsev et al. (2004). Specifically, source spectra are obtained by building images in a set of energy intervals followed by normalizing

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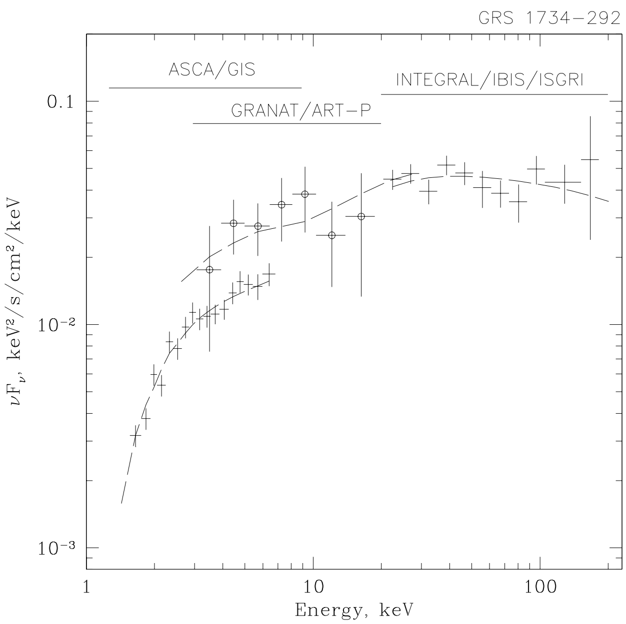

Fig. 1. Composite X-ray spectrum of GRS 1734−292 obtained from nonsimultaneous INTEGRAL, GRANAT and ASCA observations. The dashed lines indicate the best-fit (absorbed power-law+reflection) model defined by parameters given in Table 1 (the last set), scaled to match the different data sets.

Table 1. Results of spectral analysis

Power law (PL) with cutoff	IBIS
Γ	2.1 ± 0.1
$E_{\rm cut}$, keV	> 110 (2σ)
Flux (18–200 keV)[a]	1.65 ± 0.2
Flux (2–10 keV)[b]	1.3
χ^2/d.o.f	7.6/10
Absorbed PL	**GIS**
$N_{\rm H}$, 10^{22} cm^{-2}	1.5 ± 0.2
Γ	1.48 ± 0.15
Flux (2–10 keV)	0.35
χ^2/d.o.f	17.0/15
Absorbed PL with cutoff	**IBIS+GIS+ART-P**
$N_{\rm H}$, 10^{22} cm^{-2}	2.0 ± 0.3
Γ	1.7 ± 0.2
$E_{\rm cut}$	$156^{+\infty}_{-55}$
Flux (2–200 keV, IBIS)[c]	2.1
Flux (2–200 keV, GIS)[c]	1.3
Flux (2–200 keV, ART-P)[c]	2.1
χ^2/d.o.f	34.1/34
Absorbed PL with cutoff+reflection	**IBIS+GIS+ART-P**
$N_{\rm H}$, 10^{22} cm^{-2}	2.2 ± 0.2
Γ	1.9 ± 0.2
$E_{\rm cut}$	> 120 (2σ)
$R \equiv \Omega/2\pi$	1.0 (fixed)
Flux (2–200 keV, IBIS)[c]	2.2
Flux (2–200 keV, GIS)[c]	1.8
Flux (2–200 keV, ART-P)[c]	2.8
χ^2/d.o.f	34.4/34

[a] All quoted fluxes are observed (uncorrected for absorption) ones and are given in units of 10^{-10} erg s^{-1} cm^{-2}.
[b] Flux in the 2–10 keV band computed from the model assuming interstellar absorption with $N_{\rm H} = 1.5 \times 10^{22}$ cm^{-2}.
[c] Model flux in the 2–200 keV band scaled to match the IBIS, GIS or ART-P data.

the resulting source fluxes to the corresponding fluxes of the Crab for a similar position in the field of view. Our analysis of an extensive set of Crab calibration observations has shown that the source absolute flux can be recovered with an accuracy of 10% and the systematic uncertainty of relative flux measurement in different energy channels is less than 5%.

In the 2–10 keV band we used a 6-ks observation performed on March 12, 1999 with the ASCA/GIS telescope (Sakano et al. 2002). The data reduction was done using the LHEASOFT/FTOOLS 5.2 package. In the 3–20 keV range, partially overlapping with the ASCA and INTEGRAL bands, we used the published spectrum based on GRANAT/ART-P observations of GRS 1734−292 in September–October 1990 (Pavlinsky et al. 1994).

3. Results

The composite X-ray (2–200 keV) spectrum of GRS 1734−292 is shown in Fig. 1. We modeled the spectrum using the XSPEC package and the results are presented in Table 1.

The spectrum measured at 18–200 keV with INTEGRAL/IBIS is well fit by a power law with a photon index $\Gamma = 2.1 \pm 0.1$ (hereafter all quoted uncertainties are 1σ). The ASCA/GIS observation at 2–10 keV indicates a harder power law, $\Gamma = 1.48 \pm 0.15$, and requires the inclusion of neutral absorption with a column density $N_{\rm H} = (1.5 \pm 0.2) \times 10^{22}$ cm^{-2}. This column does not exceed significantly the Galactic interstellar absorption in the direction of GRS 1734−292 ($N_{\rm H} \approx 1.0 \times 10^{22}$ cm^{-2}) as estimated by Martí et al. (1998), taking into account the uncertainty in the latter value. Our results for the ASCA observation are in good agreement with those previously reported by Sakano et al. (2002).

An absorbed power law model with $\Gamma = 1.7 \pm 0.2$ modified by an exponential cutoff with $E_{\rm cut} \gtrsim 160$ keV provides a good fit to the ASCA, ART-P and IBIS data combined if allowance is made for the different flux levels in these observations. Such type of spectra is known to result from Comptonization of low energy radiation in a hot plasma (e.g. Sunyaev & Titarchuk 1980). Alternatively, the broadband spectrum of GRS 1734−292 can be well fit by an absorbed power law with a Compton reflection component (pexrav model in XSPEC) whose amplitude R is poorly constrained by the data; fixing $R = 1$ yields $\Gamma = 1.9 \pm 0.2$.

The results of the above analysis are consistent with the hypothesis that the X-ray spectrum was not significantly different in the ART-P, ASCA and INTEGRAL observations. Assuming a constant spectral shape, the X-ray flux from GRS 1734−292 varied by less than a factor of 2

from one observation to another. Figure 2 summarizes our knowledge of the X-ray light curve of the source for the period 1990–2004. This light curve includes three additional flux measurements: one based on an ASCA/GIS observation on September 8, 1998 and reported by Sakano et al. (2002), and two based on new observations of the GC region with INTEGRAL/IBIS on March 12–16 and April 8–9, 2004 (with effective exposures of 137 ks and 108 ks, respectively). The fluxes from the different instuments have been translated to the 2–200 keV range assuming the absorbed power law+reflection model from Table 1.

The presented long-term light curve suggests that GRS 1734−292 is fairly stable on a time scale of years, with a typical absorption-corrected flux of 0.7 (2.2)$\times 10^{-10}$ erg s^{-1} cm^{-2} in the 2–10 keV (2–200 keV) band. We note that GRS 1734−292 is marginally ($4\,\sigma$) detected on a similar flux level on the cumulative map of the GC region obtained from Mir/Kvant/TTM observations in 1987–1997 (M. Gilfanov, private communication). Therefore, the typical intrinsic luminosity of GRS 1734−292 is 6(20) $\times$ 10^{43} erg s^{-1} at 2–10 keV (2–200 keV) (assuming $H_0 = 75$ km s^{-1} Mpc^{-1}). During the $\sim$ 3-day long outburst detected by GRANAT/SIGMA (Churazov et al. 1992) GRS 1734−292 was apparently brighter by a factor of ~ 5.

The 1-month series of INTEGRAL observations in 2003 allows us to study the variability of GRS 1734−292 on time scales of days (see Fig. 2). The source proves to be variable, with a fractional variability amplitude of $12 \pm 6\%$ at frequencies higher than 6×10^{-7} Hz. These results demonstrate that GRS 1734−292 is similar in its long-term and short-term variability properties to other Seyferts (e.g. Markowitz et al. 2003).

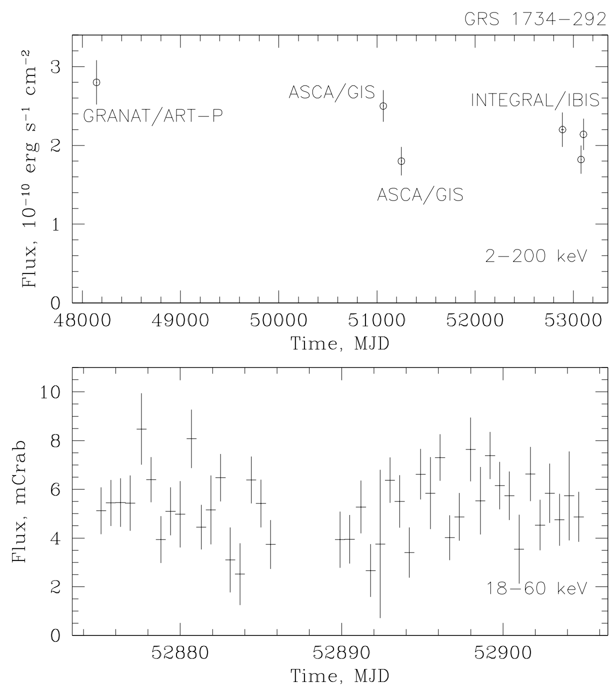

Fig. 2. Upper panel: Time history of the observed X-ray flux from GRS 1734−292 in 1990–2004 assuming that its broadband X-ray spectrum remained invariably as that shown in Fig. 1. **Lower panel**: Light curve of GRS 1734−292 in August–September 2003 measured with INTEGRAL/IBIS.

4. Discussion

The obtained X-ray spectrum of GRS 1734−292 is typical for Seyfert galaxies. Previous hard X-ray missions including GRANAT, CGRO, RXTE and BeppoSAX demonstrated that X-ray spectra of Seyferts can be described by a power law of $\Gamma \approx 1.8$ modified by Compton reflection at 10–100 keV and an exponential cutoff at $E_{\rm cut} \gtrsim$ 100–200 keV (Jourdain et al. 1992; Eracleous et al. 2000; Gondek et al. 1996; Perola et al. 2002). Measurement of the cutoff energy in individual objects remains a difficult task even for INTEGRAL, feasible only for very long exposures of the brightest AGNs. Accumulation of statistics on the distribution of $E_{\rm cut}$ values and its dependence on luminosity (and possibly other characteristics) is crucial for constraining the physical parameters of the hot plasma surrounding supermassive black holes as well as for a better understanding of the origin of the cosmic X-ray background (CXB). The lower limit $E_{\rm cut} \gtrsim 100$ keV obtained here for GRS 1734−292 is thus valuable given the fact that this source is one of the most luminous AGNs for which such an estimate has been made and also because the bulk of the CXB appears to be produced by AGNs with similar ($\sim 10^{44}$ erg s^{-1}) luminosities (Ueda et al. 2003).

We finally discuss the possibility that GRS 1734−292 is a BL Lac object, as suggested by its positional coincidence with the gamma-ray source 3EG J1736−2908. There are two arguments against this hypothesis. First, the optical spectrum of GRS 1734−292 is completely dominated by broad lines characteristic of Seyfert 1s (Martí et al. 1998). This contrasts with the usual situation for BL Lac objects, when it is very difficult to discern any emission lines against the strong continuum collimated toward us. Secondly, radio observations show only a weak source at the GRS 1734−292 position, with a flux $\sim$ 10 mJy at 10 GHz (Martí et al. 1998) . If GRS 1734−292 were a typical BL Lac object, one would expect its radio counterpart to be some 3 orders of magnitude stronger (Fossati et al. 1998). This is demonstrated in Fig. 3, where the broadband spectral energy distribution (SED) of GRS 1734−292 is compared with the composite SED of BL Lac objects of similar X-ray luminosity. On the other hand, the radio to X-ray spectrum of GRS 1734−292 is very similar to that of the architypal Seyfert 1 galaxy NGC 4151 (see Fig. 3).

Therefore, either 1) GRS 1734−292 is a quite unusual Seyfert 1 galaxy producing strong gamma-ray emission or 2) it has no relation to 3EG J1736−2908. Given that the number density of hard X-ray sources detected by INTEGRAL in the central $5^\circ \times 5^\circ$ region of the Galaxy is $\sim$ 0.5 sq. deq^{-1} (Revnivtsev et al. 2004), the probability of finding by chance an INTEGRAL source within

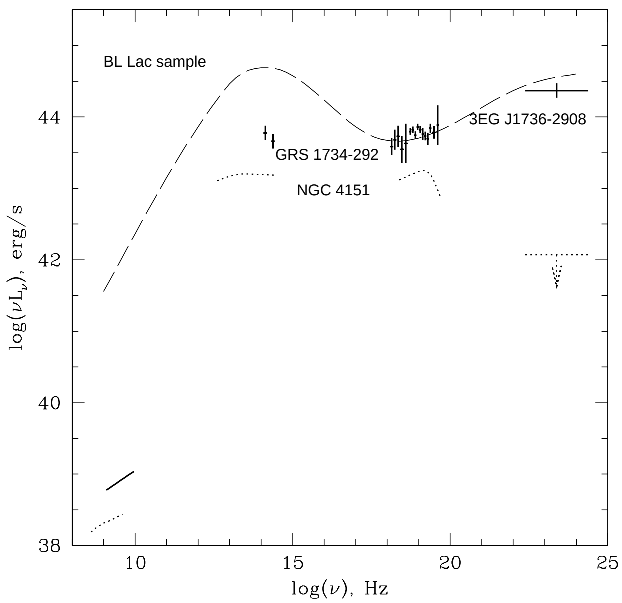

Fig. 3. Comparison of the broadband spectral energy distribution of GRS 1734−292 (in solid) with those of NGC 4151 (in dotted) and of BL Lac objects (in dashed). The data for GRS 1734−292 include the radio spectrum and near infrared measurements (K and H bands) adopted from Martí et al. (1998), X-ray spectrum at 5–200 keV from GRANAT/ART-P and INTEGRAL/IBIS and the gamma-ray flux measured from 3EG J1736−2908 with CGRO/EGRET in July–August, 1992 (Hartman et al. 1999). For NGC 4151, the radio to optical spectrum is approximated from multifrequency data taken from the NED database, the X-ray spectrum above 10 keV is adopted from Finoguenov et al. (1995), the upper limit on the flux above 100 MeV is taken from Lin et al. (1993), and a distance of 20 Mpc is assumed. The composite SED for BL Lac objects is adopted from Fossati et al. (1998), specifically from the sample characterized by radio luminosities of 10^{42}–10^{43} erg s^{-1}, which closely matches the SED of GRS 1734−292 in the X-ray range; these data were recalculated to our adopted value $H_0 = 75\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.

the error box of 3EG J1736−2908 is $\sim 50\%$. On the other hand, the EGRET map (Hartman et al. 1999) of the central ($\sim 10^\circ \times 10^\circ$) region of the Galaxy indicates that the probability of finding by chance an EGRET source consistent with the position of GRS 1734−292 is only $\sim 3\%$. The upcoming GLAST mission will be able to localize the gamma-ray source down to $\sim 1'$ and thus settle the issue of GRS 1734−292/3EG J1736−2908 association.

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